

OPTIMIZATION OF WEDM PARAMETERS USING TAGUCHI METHOD AND FUZZY LOGIC TECHNIQUE FOR AL-6351

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ABSTRACT

Optimization is one of the techniques used in the manufacturing sector to achieve best operating conditions, which is essential for industries to provide quality stuff at subordinate outlay. This paper aims investigation and optimization of Wire electronic discharge machine (WEDM) parameters using optimization technique i.e. Taguchi method and Fuzzy logic. Three parameters preferred are P_{ON} (Pulse ON), P_{OFF} (Pulse OFF), and F_R (Feed Rate). L_9 orthogonal array and fuzzy logic are selected to study the effect on main factors. The effect of input parameters and relationship between them to the material removal rate (MRR) and optimum surface roughness are calculated by using Taguchi method and Fuzzy logic technique.

KEYWORDS: Taguchi Method, Fuzzy Logic, WEDM, SR, MRR & Aluminium Alloy

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INTRODUCTION

As per WEDM operation, a thin charged wire is held between mechanical guides i.e. Upper and lower that forms one electrode, material being cut forms second electrode. Sparks produced through electric discharge between wire and the work-piece. The cutting debris are exhausted out by the wire and the work-piece which are dipped in de-ionized fluid (American Wire EDM, Inc., 1985)

WEDM is a non-conventional machining process, there is no physical contact between the electrode and the work-piece to be cut. As the charged wire makes no physical contact with the work-piece in EDM machining hence no cutting force is involved (S.G. & B.M., 2015) and eradicated all kinds of stress, vibration and chatter problems (Joshi, 2011). The highly accurate and precise machining parts are not possible through traditional machining. Nowadays, WEDM is widely used in production of complex shaped components used in different industries such as aerospace, automobile and other industrial application (Dongguan Lemo Precision Metal Products Co.,Ltd, 2002)

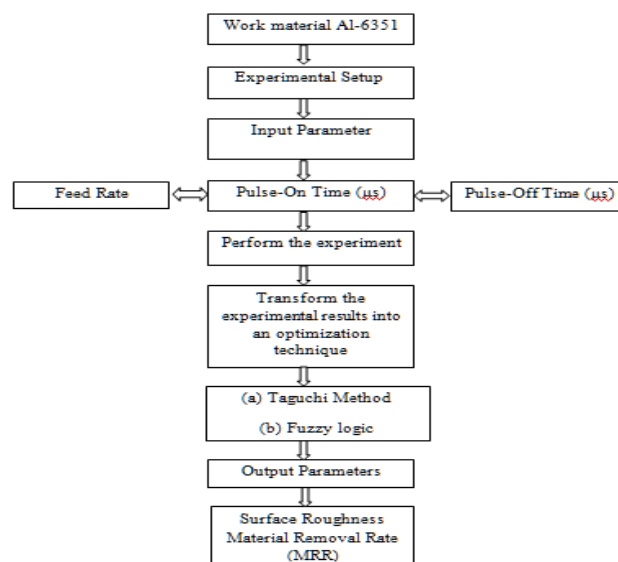
À_l' instant manufacturing practice is achieved by simulating the process to real conditions before manufacture. Traditional trial and error methods are being replaced by number of simulation tools. Process parameter optimization is an important criterion in machining process to achieve quality product. Taguchi method of optimizing performance characteristics of process parameter is used to achieve quality (Ross, 1996; Taguchi, 1990). Optimization of performance characteristics can be achieved by the Taguchi method through the setting of process parameters and reduction in sensitivity of the system performance to source of variation. As a result, Taguchi method has become a powerful tool in the design of experiment methods (Bagchi, 1993). The meaning of

performance characteristics such as lower-the-better, higher-the-better and nominal-the-better contains a certain degree of uncertainty and imprecision (Rajyalakshmi & Venkata Ramaiah, 2013), the theory of fuzzy logic initiated by Zadeh in 1965 (Klir & Yuan, 2002) has proven to be practical for dealing with such uncertainty and imprecision in information. (Tzeng Y) describe the application of the fuzzy logic analysis coupled with Taguchi methods to optimize the exactitude and correctness of the high-speed EDM process.

Present work uses an efficient approach of using Taguchi method with fuzzy logic for the determination of the optimal machining parameters in the EDM process. In this work, EDM process is described, after which the experimental details of using the Taguchi method with fuzzy logic to optimize the electrical machining process to achieve high MRR (Material removal rate) and Low surface roughness (SR) are given.

Setup and Procedure

The experiment was carried out on FANUC Robocut α -1iE CNC WEDM machine. Present research work considered WEDM of AL-6351 in setting the machining parameters, particularly in rough cutting operation, the main objective is the maximization of MRR, minimization of SR.



Optimization of cutting parameters of a WEDM has been attained for aluminium 6351. An optimized value of MRR and SR has been achieved for the machining factors Pulse On, Pulse Off and Feed Rate using Fuzzy Taguchi based approach.

Aluminium alloy AL 6351 is a medium Strength alloy with excellent corrosion Resistance. It has the highest strength. Alloy AL 6351 is known as a structural alloy (Santhanakrishnan, Sivasakthivel, & Sudhakaran, 2017). The chemical composition of the AL 6351 is given in table1.

Table 1: Chemical Composition of AL-6351

Si	Fe	Cu	Mn	Mg	Ti	Pb	Sn	Cr	Al	Others
.461	.253	.025	.0567	.4187	.0373	.0026	.0016	.0236	98.62	.10

The addition of a large amount of manganese controls the Grain structure which in turn results in a stronger alloy.

The mechanical properties of the Al 6351 are listed below in table2.

Table 2: Mechanical Properties of AL 6351

Material	AL- 6351
Density ($\times 1000 \text{kg/m}^3$)	2.6-2.8
Young Modulus (GPa)	70-80
Tensile Strength (MPa)	250
Strength (MPa)	150
Hardness (HB500)	95

Light unit weight, strength 1/3rd comparable to archetypal other aluminium alloys, brilliant corrosion resistance even in the occurrence of rain and other severe conditions, high toughness and resistance to low-ductility fracture even at very low temperature and free of any ductile-to-brittle transition that has sometimes been fatal to older structures with excellent fabric ability makes it eligible for aircraft structures, manufacture of aerospace structures, superior corrosion resistance eliminates the need to paint the aluminium components, toughness eliminates concerns about brittle fracture even in the most severe arctic weather.

Setting of machining parameters relies a lot on the experience of the operators. In practice, it is very difficult to utilize the machine optimally due to its many adjustable parameters. To address this difficulty, statistically designed experiments (Savadamuthu, Muthu, Rakhul, & Jothimani, 2013) is used for investigating the effect of process parameters on MRR and SR. Finally, Fuzzy based Taguchi approach has been adopted for the evaluation of optimal process parameters.



Figure 1: FANUC ROBOCUT α-11e WEDM

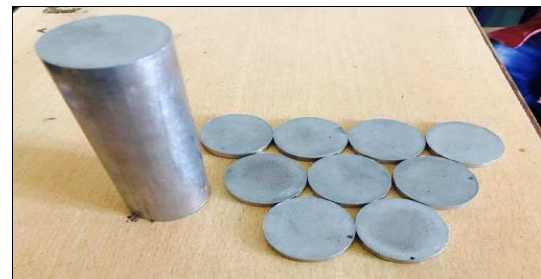


Figure 2: Specimen Used for Experimental Study



Figure 3: Specimen in Machining Operation Before Cutting



Figure 4: Specimen During Machining

Experimental Factors and Their Levels

Table3: The Levels of Machining Parameters

Factor	Parameter	Symbol	Level I	Level II	Level III
I	P _{ON} Time	P _{ON} (μs)	3	10	16
II	P _{OFF} Time	P _{OFF} (μs)	22	55	88
III	Feed Rate	F _R (m/min)	6.440	8.005	9.570

Statistical analysis of this study is done using Minitab software. All steps involved for DOE analysis is shown in heading.

Table 4: Orthogonal Array (L9)

S.No.	F _R	P _{ON}	P _{OFF}	Experimental (μm) R _a	Experimental MMR(mm/min)
1	6.440	3	22	4.2170	125.020
2	6.440	3	22	3.8520	127.281
3	6.440	3	22	3.8650	121.163
4	6.440	10	55	3.6360	116.215
5	6.440	10	55	3.7060	98.553
6	6.440	10	55	3.8680	85.652
7	6.440	16	88	3.8160	106.280
8	6.440	16	88	3.8840	104.272
9	6.440	16	88	5.0550	106.439
10	8.005	3	22	4.4206	87.248
11	8.005	3	22	4.5410	89.509
12	8.005	3	22	4.6609	90.706
13	8.005	10	55	4.7059	97.622
14	8.005	10	55	4.7452	99.484
15	8.005	10	55	4.7854	102.144
16	8.005	16	88	4.8247	104.006
17	8.005	16	88	4.7851	107.730
18	8.005	16	88	4.7818	110.656
19	9.570	3	22	4.7740	112.651
20	9.570	3	22	4.8340	113.316
21	9.570	3	22	4.8565	116.774
22	9.570	10	55	5.2241	122.493
23	9.570	10	55	5.2988	122.759
24	9.570	10	55	5.4459	124.222
25	9.570	16	88	5.6125	125.286
26	9.570	16	88	5.6876	125.951
27	9.570	16	88	5.8067	126.749

For the following, regression equation is used for roughness as follows

$$\text{Roughness} = 4.27 + 0.015 \text{ Feed Rate} + 0.0186 \text{Pulse off} - 0.081 \text{ Pulse On}$$

Table 5: Regression Analysis: Roughness versus Feed Rate, Pulse Off, Pulse On

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	0.44854	0.149512	0.72	0.580
Feed rate	1	0.00037	0.000371	0.00	0.968
P _{OFF}	1	0.02142	0.021419	0.10	0.761
P _{ON}	1	0.09758	0.097583	0.47	0.523
Error	5	1.03424	0.206848		

Table 5: Contd.,					
Total	8	1.48278			

Table 6: Model Summary Surface Finish

S	R-sq	R-sq(adj)	R-sq(pred)
0.454806	30.25%	0.00%	0.00%

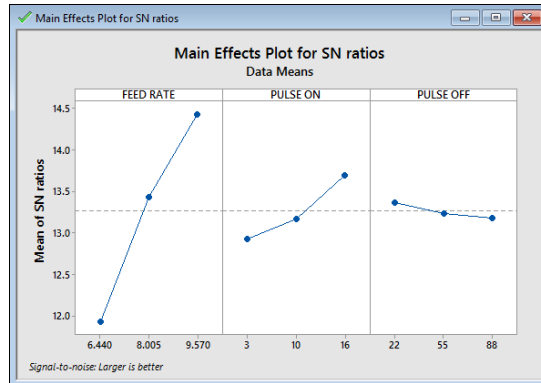


Figure 5: S/N Ratio for Surface Roughness

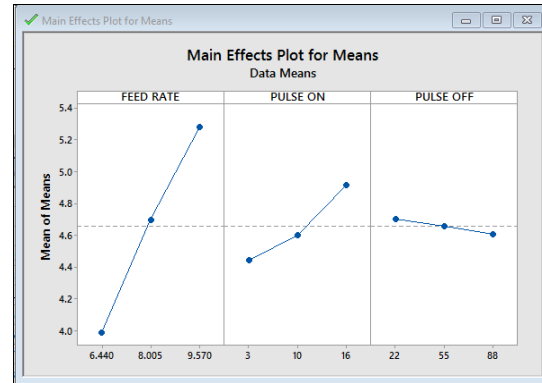


Figure 6: Main Effects Plot for Means

Regression Equation for MRR

$$\text{MRR} = 0.00462 - 0.000036 \text{ pulse on} + 13.2997 \text{ Feed Rate} - 0.000064 \text{ Pulse Off}$$

Table 7: Regression Analysis: MRR versus PULSE ON, FEEDRATE, PULSE OFF

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	1470.58	490.192	6.619E+09	0.000
Cutting Speed	1	0.00	0.000	0.26	0.0.629
Feed	1	283.28	283.282	3.825E+09	0.000
Depth of Cut	1	0.00	0.000	3.49	0.0.121
Error	5	0.00	0.000		
Total	8	1470.58			

Table 8: Model Summary MRR

S	R-sq	R-sq(adj)	R-sq(pred)
0.0002721	100.00%	100.00%	100.00%

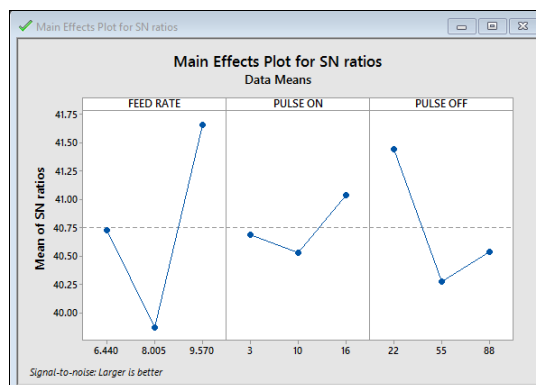


Figure 7: S/N Ratio for Material Removal Rate

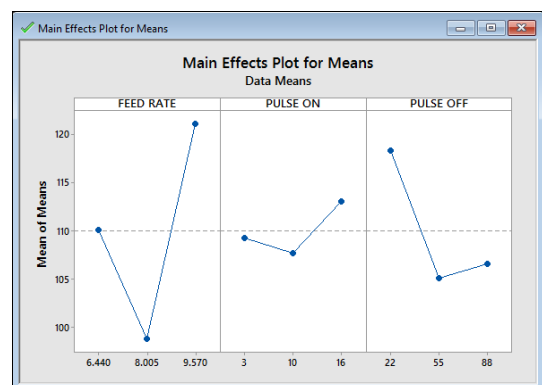


Figure 8: Main Effects Plot for Means

Fuzzy Logic

A fuzzy logic unit involve a fuzzifier, membership functions, a fuzzy rule base, an inference engine and a defuzzifier. A fuzzifier through membership function fuzzify the S/N ratios. Fuzzy reasoning on fuzzy rules is (The open archive HAL) performed by inference engine to generate fuzzy value. The function of defuzzifier is to convert the fuzzy values into a MRPI. If-then control rules with three inputs, x_1 , x_2 and x_3 and one output y , i.e.

Rule 1: if x_1 is A_1 and x_2 is B_1 and x_3 is C_1 then y is D_1 else

Rule 2: if x_1 is A_2 and x_2 is B_2 and x_3 is C_2 then y is D_2 else

Rule n: if x_1 is A_n and x_2 is B_n and x_3 is C_n then y is D_n .

A_i , B_i , C_i , and D_i are fuzzy subsets defined by the corresponding membership functions with input, Figure 9 to Figure 11.

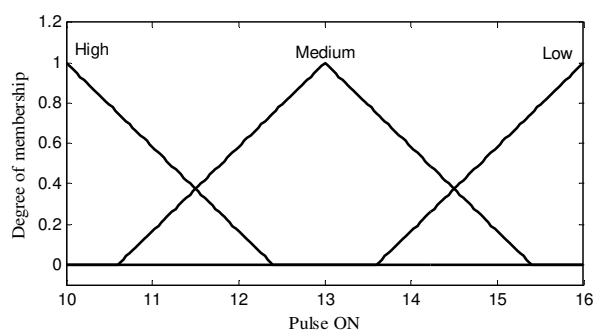


Figure 9: Pulse ON Vs. Degree of Membership Function

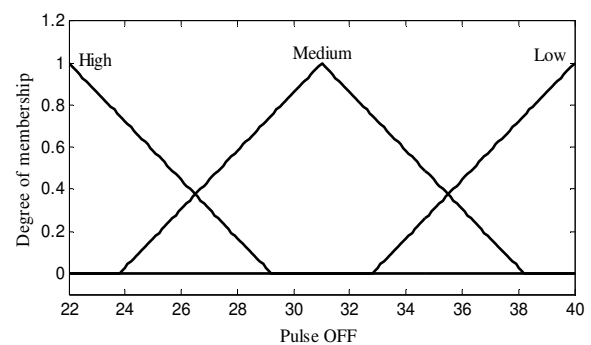


Figure 10: Pulse OFF Vs. Degree of Membership Function

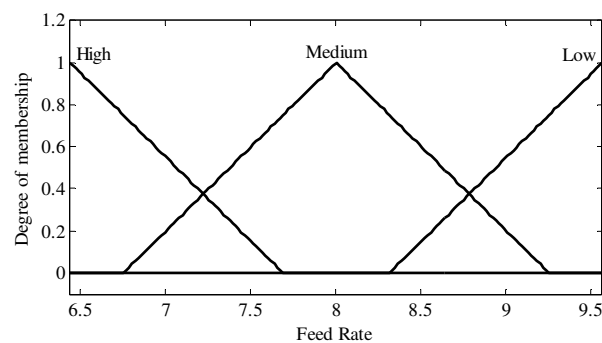


Figure 11: Feed Rate Vs Degree of Membership Function

Result of MRR and surface roughness by fuzzy logic is tabulated under table 9 and Response of result is tabulated under Table 10 and 11 in which results of experiments, model equation and fuzzy logic for roughness and MRR is shown. Output range for MRR and surface roughness also shown in figure 12 and 13. Figure 14 and 15 shows Graph of variation of Surface roughness for experimental model and fuzzy logic and graph of variation of measured MRR and theoretical MRR.

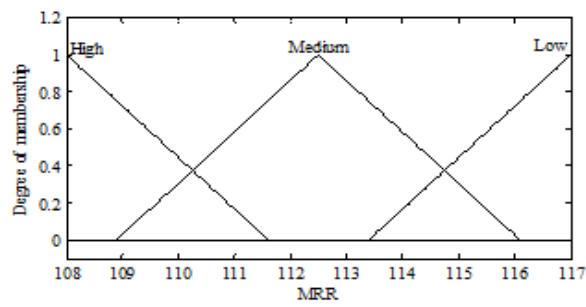


Figure 12: MRR VS. Degree of Membership Function

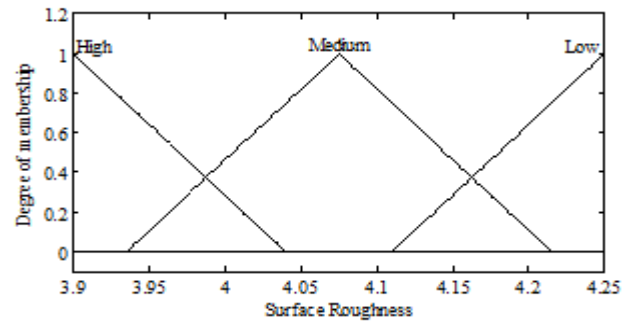


Figure 13: Surface Roughness VS. Degree of Membership Function

Table 9: Results of MRR and Surface Roughness by Fuzzy Logic

S No.	Pulse ON	Pulse OFF	Feed Rate	MRR	Roughness
1	11	22	9.400	116	4.07
2	12	25	9.570	117	4.04
3	13	28	9.110	113	4.02
4	14	30	8.738	113	3.99
5	15	32	7.410	110	4.00
6	16	34	6.440	108	4.00
7	10	36	7.991	113	4.25
8	10	38	7.840	111	4.25
9	10	40	8.003	109	4.25

Table 10: Results of Experiments, Model Equation and Fuzzy Logic for Surface Roughness

No of Experiment	Experimental R_a (mm)	Model Equation R_a (mm)	Fuzzy Equation R_a (mm)
1	4.217	3.929	4.070
2	3.852	3.906	4.040
3	3.865	3.874	4.020
4	3.636	3.825	3.990
5	3.706	3.761	4.000
6	3.868	3.703	4.000
7	3.816	4.240	4.250
8	3.884	4.280	4.250
9	5.055	4.324	4.250

Table 11: Results of Experiments, Model Equation and Fuzzy Logic for MRR

No of Experiment	Experimental MRR	Model Equation MRR	Fuzzy Logic MRR
1	125.02	125.01	116
2	127.28	127.28	117
3	121.16	121.16	113
4	116.21	116.21	113
5	98.55	98.15	110
6	85.65	85.55	108
7	106.28	106.27	113
8	104.27	104.27	111
9	106.43	106.44	109

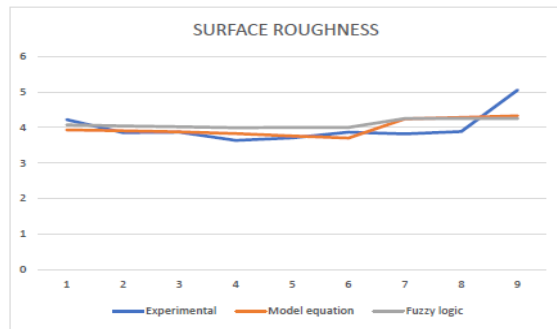


Figure 14: Variation of Surface Roughness for Model Experimental and Fuzzy Logic

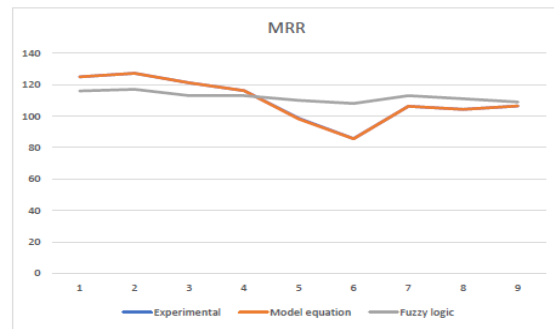


Figure 15: Variation of Measured MRR and Theoretical MRR

In this analytical experiment, Taguchi Fuzzy based approach has been used to find the effects of different machining parameters like P_{ON} , P_{OFF} and Feed Rate on response parameters like Surface roughness (R_a) and Material removing rate (MRR). Variation in different process parameters creates variations in various response parameters.

Best and worst cases are shown in table 12 and 13 for surface roughness and MRR, which shows that the Feed rate is most important factor for determining surface roughness and the most important factor that determines the MRR of a WEDM are Pulse OFF and Feed rate.

Table 12: Best and Worst Case for Surface Roughness

Condition	Experimental R_a (mm)	Model Equation R_a (mm)	Fuzzy Logic R_a (mm)
Best	5.055	4.374	4.25
Worst	3.636	3.825	3.99

Table 13: Best and Worst Case for Material Removal Rate (MRR)

Condition	Experimental MRR	Model Equation MRR	Fuzzy Logic MRR
Best	85.625	85.552	108
Worst	125.02	125.01	116

CONCLUSIONS

It can be concluded that the Taguchi Fuzzy approach can be used as an effective technique for the optimization of machining parameters. It can also be concluded that P_{ON} , P_{OFF} , Feed Rate can be the influencing factors for optimizing the MRR and surface roughness for aluminium 6351. The most optimized value of MRR was attained at the Pulse On value for 10 micro seconds, Pulse Off value of 40 micro seconds and feed rate of 8.00 mm/min, whereas the most optimum value for SR was attained at the pulse On value of 16, Pulse Off value of 34 and Feed rate of 6.44 mm/min.

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